



US008948978B2

(12) **United States Patent**
Liu et al.

(10) **Patent No.:** **US 8,948,978 B2**
(45) **Date of Patent:** ***Feb. 3, 2015**

(54) **SYSTEM AND METHOD FOR MACHINE CONTROL**

(56) **References Cited**

U.S. PATENT DOCUMENTS

(75) Inventors: **Forrest Liu**, Peoria, IL (US); **William L. Ostler**, Chillicothe, IL (US)

5,469,646	A	11/1995	Takamura	
6,064,933	A	5/2000	Roche	
6,845,311	B1 *	1/2005	Stratton et al.	701/50
7,364,003	B2	4/2008	Holt	
7,953,559	B2	5/2011	Sundermeyer	
2009/0018730	A1	1/2009	Tarasinski	
2009/0088931	A1 *	4/2009	Budde et al.	701/50
2009/0159302	A1 *	6/2009	Koch et al.	172/2
2012/0239260	A1 *	9/2012	Ishikawa et al.	701/50

(73) Assignee: **Caterpillar Inc.**, Peoria, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 258 days.

This patent is subject to a terminal disclaimer.

FOREIGN PATENT DOCUMENTS

WO WO2013158079 A1 * 10/2013 F15B 21/08

* cited by examiner

Primary Examiner — Calvin Cheung

(74) *Attorney, Agent, or Firm* — Baker Hostetler

(21) Appl. No.: **13/545,544**

(22) Filed: **Jul. 10, 2012**

(65) **Prior Publication Data**

US 2014/0019013 A1 Jan. 16, 2014

(51) **Int. Cl.**

G06F 7/70 (2006.01)

E02F 9/20 (2006.01)

(52) **U.S. Cl.**

CPC **E02F 9/2025** (2013.01)

USPC **701/50**

(58) **Field of Classification Search**

CPC **E02F 9/2025**

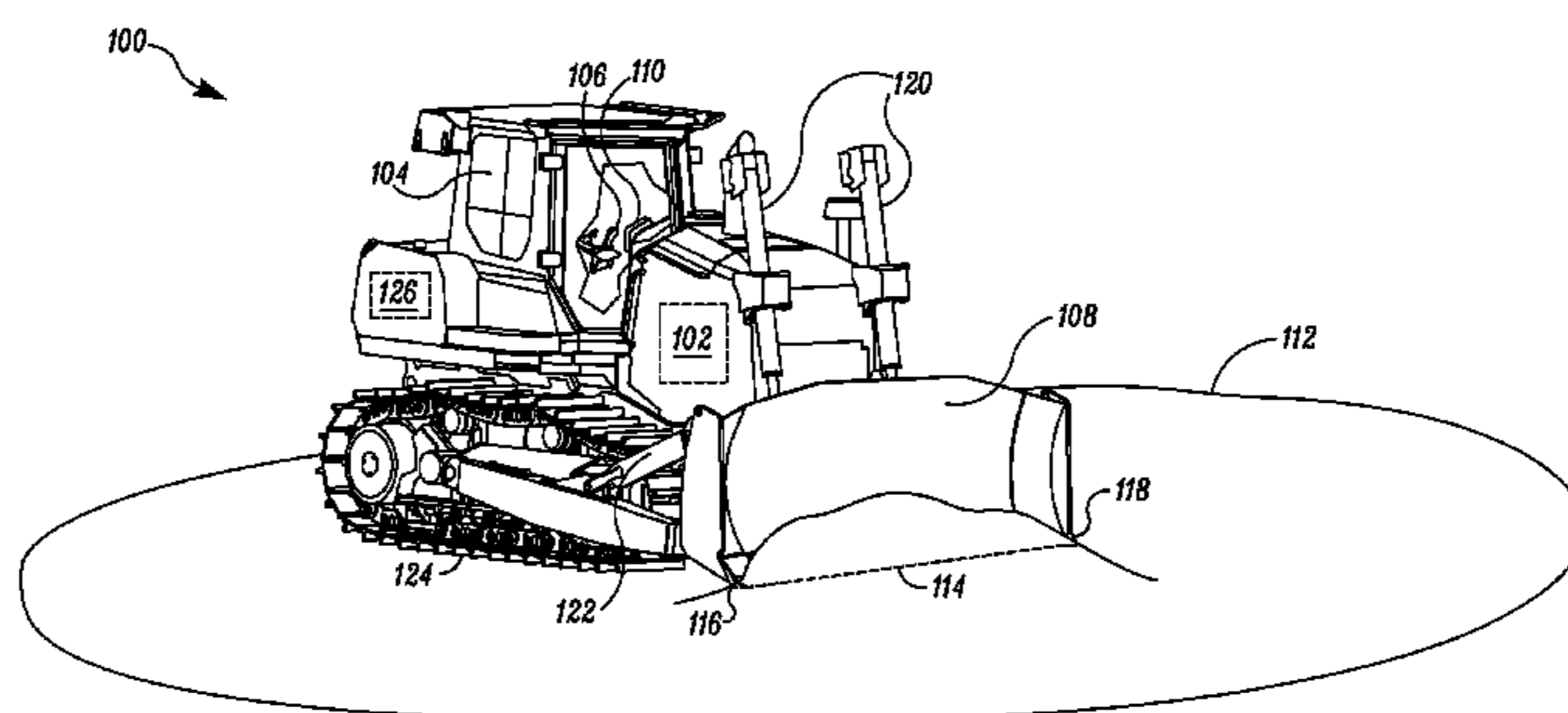
USPC **701/50**

See application file for complete search history.

(57) **ABSTRACT**

The disclosure describes a control system for controlling the movement of an implement associated with a machine. The control system includes a load sensor, a grade control system, an implement position sensor, and a controller. The load sensor is configured to generate a load signal indicative of a loading condition of the implement. The grade control system is configured to generate a desired implement position signal indicative of a desired implement position. The implement position sensor is configured to generate an implement position signal indicative of a position of the implement. The controller is configured to generate a machine control command to move the implement as a function of the load signal, the desired implement position signal, and the implement position signal.

17 Claims, 4 Drawing Sheets



[P]	Load Factor 1	Load Factor 2	Load Factor 3	Load Factor 4	Load Factor 5
Speed Parameter 1	Gp11	Gp12	Gp13	Gp14	Gp15
Speed Parameter 2	Gp21	Gp22	Gp23	Gp24	Gp25
Speed Parameter 3	Gp31	Gp32	Gp33	Gp34	Gp35
Speed Parameter 4	Gp41	Gp42	Gp43	Gp44	Gp45
Speed Parameter 5	Gp51	Gp52	Gp53	Gp54	Gp55

[I]	Load Factor 1	Load Factor 2	Load Factor 3	Load Factor 4	Load Factor 5
Speed Parameter 1	GI11	GI12	GI13	GI14	GI15
Speed Parameter 2	GI21	GI22	GI23	GI24	GI25
Speed Parameter 3	GI31	GI32	GI33	GI34	GI35
Speed Parameter 4	GI41	GI42	GI43	GI44	GI45
Speed Parameter 5	GI51	GI52	GI53	GI54	GI55

[D]	Load Factor 1	Load Factor 2	Load Factor 3	Load Factor 4	Load Factor 5
Speed Parameter 1	Gd11	Gd12	Gd13	Gd14	Gd15
Speed Parameter 2	Gd21	Gd22	Gd23	Gd24	Gd25
Speed Parameter 3	Gd31	Gd32	Gd33	Gd34	Gd35
Speed Parameter 4	Gd41	Gd42	Gd43	Gd44	Gd45
Speed Parameter 5	Gd51	Gd52	Gd53	Gd54	Gd55

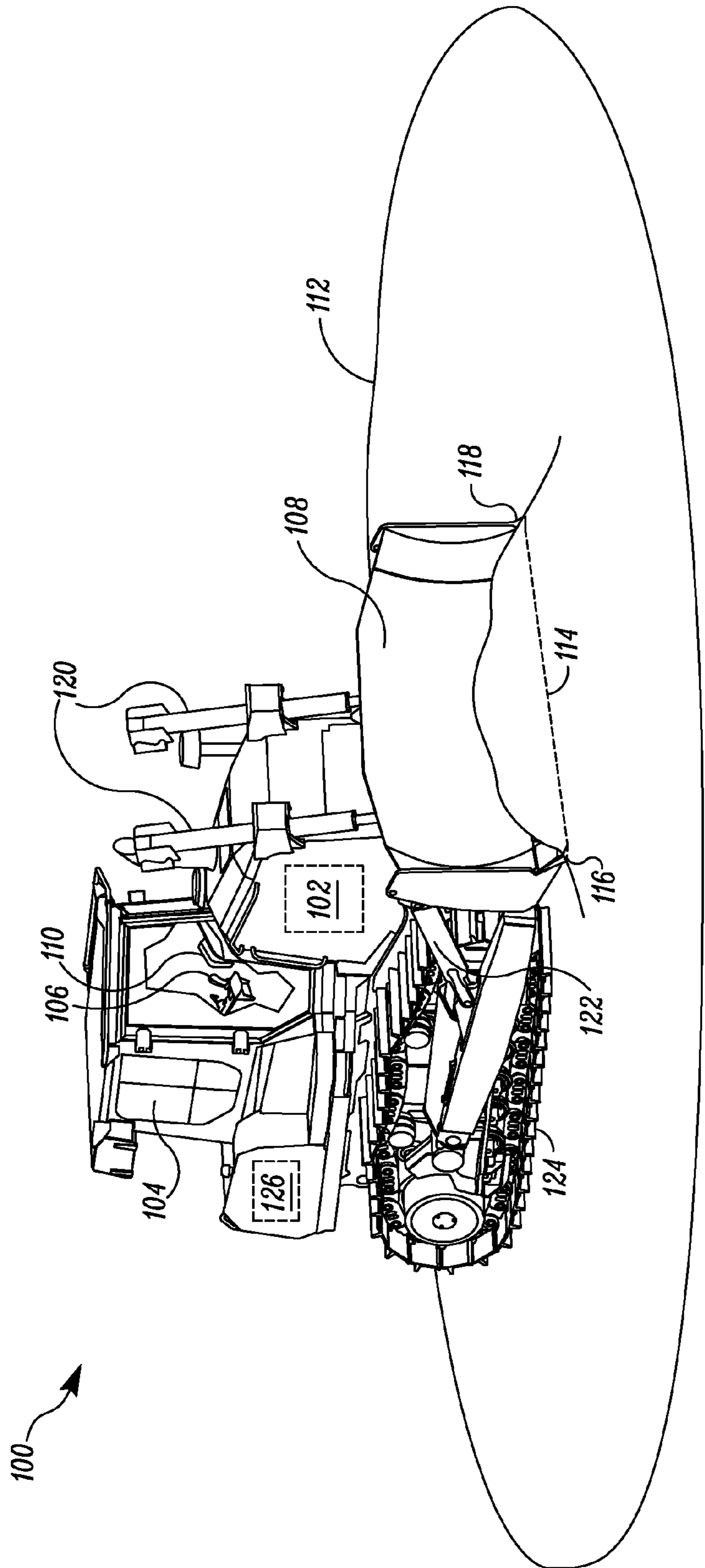


FIG. 1

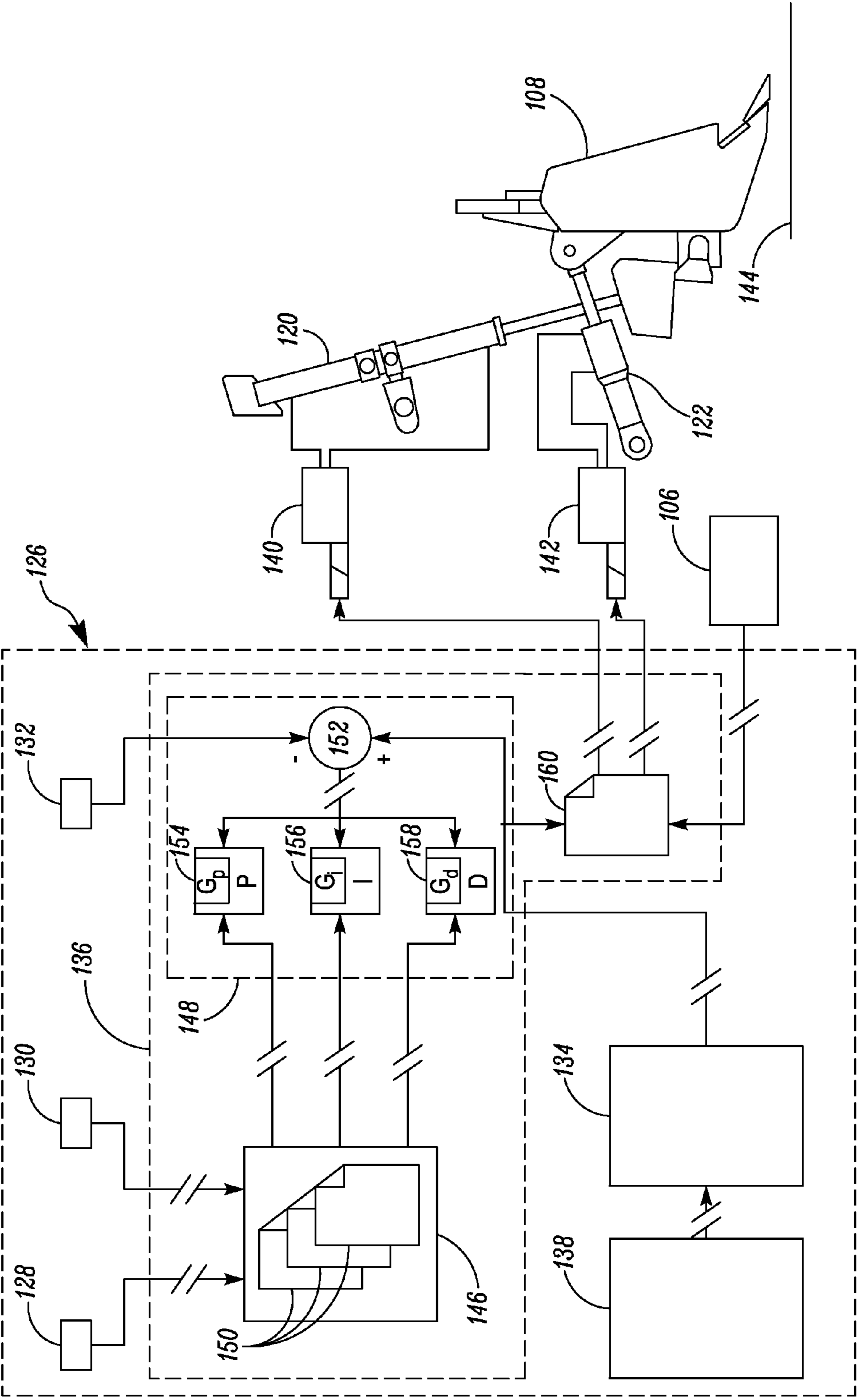


FIG. 2

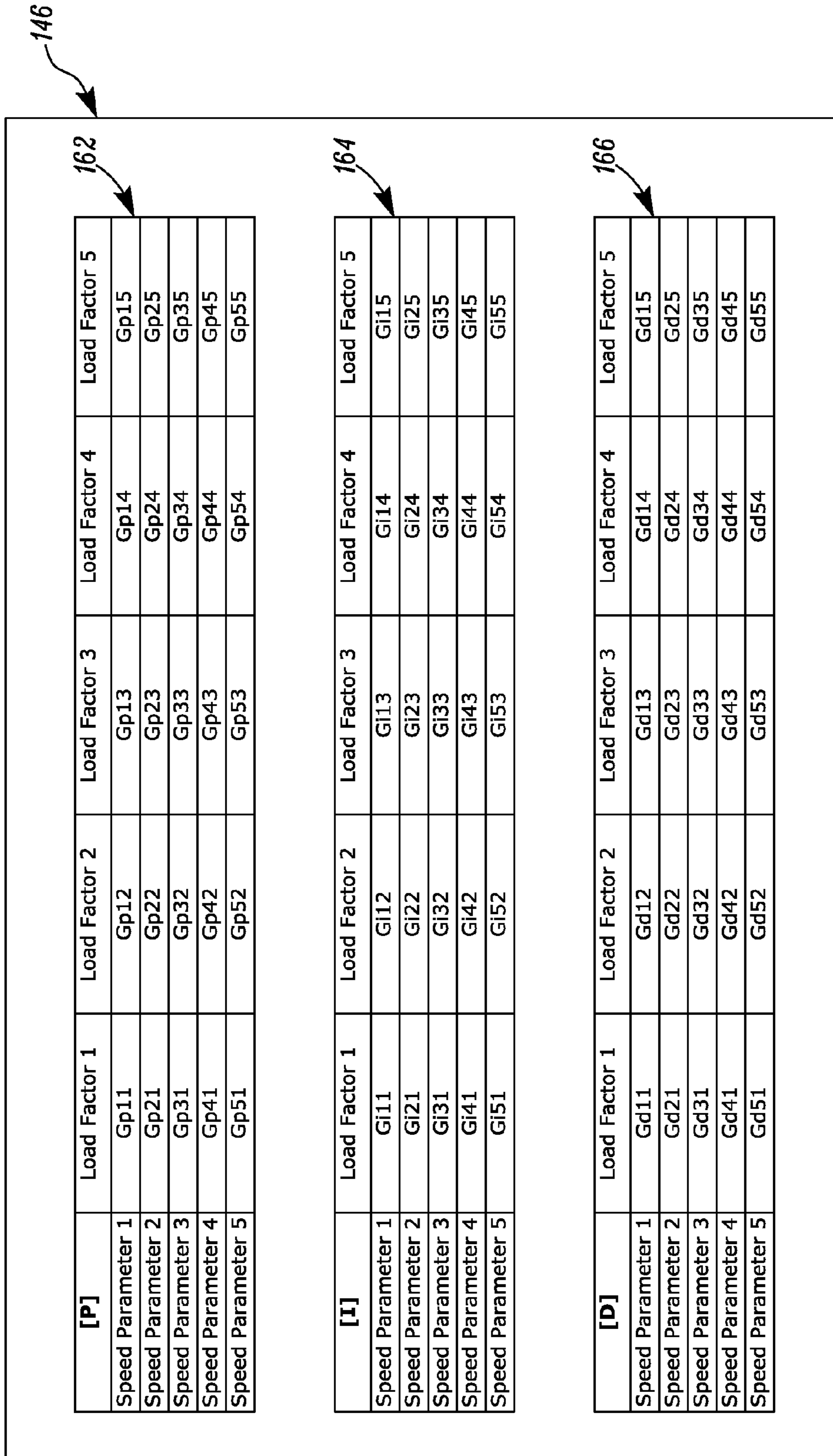


FIG. 3

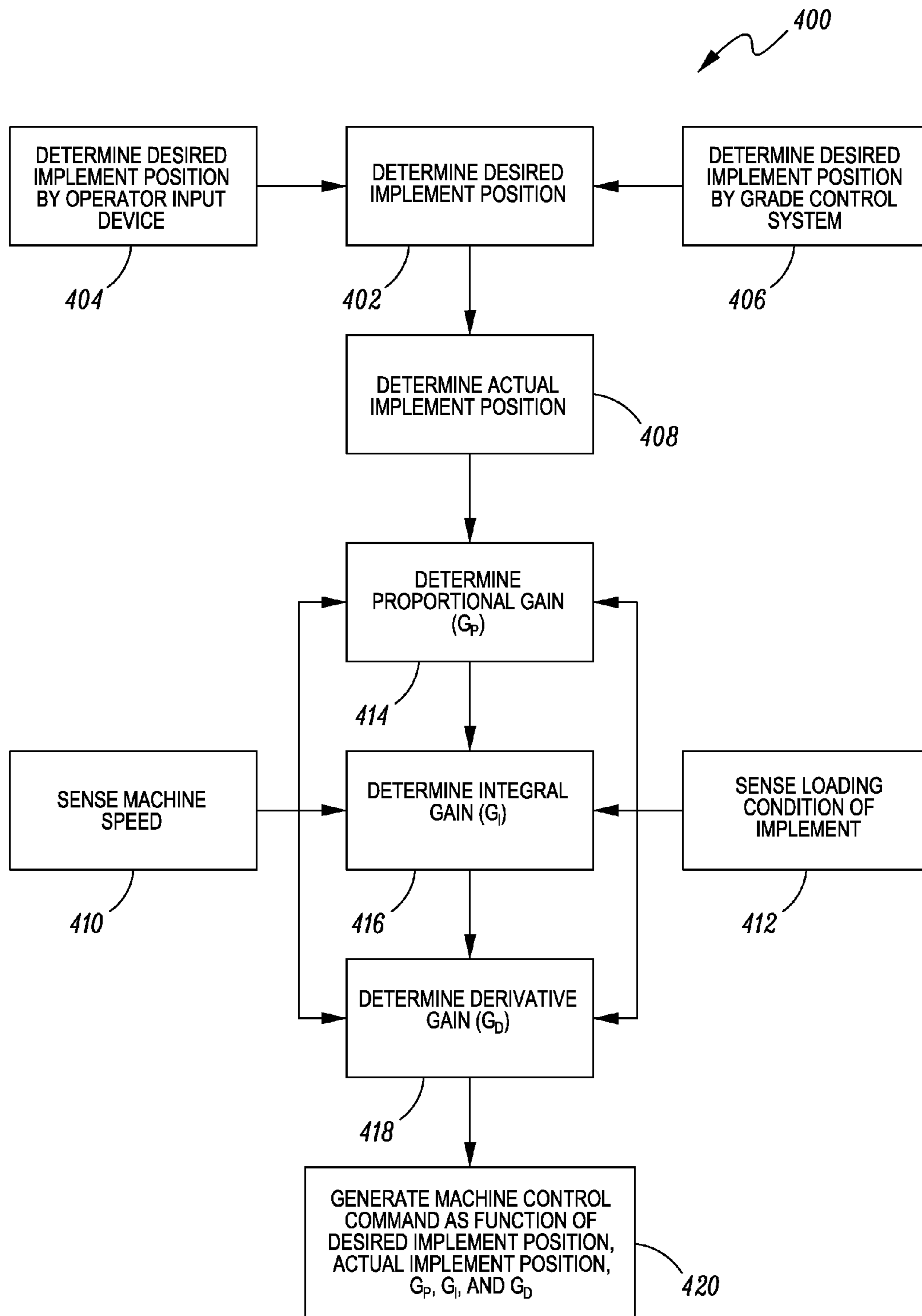


FIG. 4

1**SYSTEM AND METHOD FOR MACHINE CONTROL**

TECHNICAL FIELD

The present disclosure relates generally to a control system, and more particularly to systems and methods for controlling an implement to maximize machine productivity and protect/improve a final grade.

BACKGROUND

Earthmoving machines such as track type tractors, motor graders, scrapers, and/or backhoe loaders, have an implement such as a dozer blade or bucket, which is used on a worksite in order to alter a geography or terrain of a section of earth. The implement may be controlled by an operator or by an autonomous grade control system to perform work on the worksite. For example, the operator may move an operator input device that controls the movement of the implement using one or more hydraulic actuators. To achieve a final surface contour or a final grade, the implement may be adjusted to various positions by the operator or the grade control system.

Positioning the implement, however, is a complex and time-consuming task that requires expert skill and diligence if the operator is controlling the movement. Thus, it is often desirable to provide the autonomous grade control system for the implement to simplify the operator control. Prior art systems that automatically control the implement are known. For example, U.S. Pat. No. 6,064,933 discloses an automatic control system for positioning the implement of an earthmoving machine in accordance with a stored sequence of control command signals.

SUMMARY

Disclosed is a control system for controlling the movement of an implement associated with a machine. The control system includes a load sensor, a grade control system, an implement position sensor, and a controller. The load sensor is configured to generate a load signal indicative of a loading condition of the implement. The grade control system is configured to generate a desired implement position signal indicative of a desired implement position. The implement position sensor is configured to generate an implement position signal indicative of a position of the implement. The controller is configured to generate a machine control command to move the implement as a function of the load signal, the desired implement position signal, and the implement position signal.

Further disclosed is a method for controlling the movement of an implement associated with a machine. The method includes sensing a loading condition of the implement, determining a desired implement position with a grade control system, sensing a position of the implement, and generating a machine control command to move the implement as a function of the loading condition of the implement, the desired implement position, and the position of the implement.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a machine having a control system in accordance with an exemplary embodiment of the present disclosure;

2

FIG. 2 illustrates the control system to control the movement of an implement in accordance with an exemplary embodiment of the present disclosure;

FIG. 3 illustrates a modulation map in accordance with an exemplary embodiment of the present disclosure; and

FIG. 4 illustrates a process flow diagram for an exemplary method to control a movement of an implement, according to an aspect of the present disclosure.

DETAILED DESCRIPTION

Reference will now be made in detail to specific embodiments or features, examples of which are illustrated in the accompanying drawings. Generally, corresponding reference numbers will be used throughout the drawings to refer to the same or corresponding parts.

The present disclosure relates to systems and methods for controlling an implement to maximize machine productivity. An exemplary embodiment of a machine **100** is shown schematically in FIG. 1. The machine **100** may be a mobile machine that performs operations associated with industries such as mining, construction, farming, transportation, or the like. For example, the machine **100** may be a track type tractor or dozer, as depicted in FIG. 1, a motor grader, or other earth-moving machine known in the art. While the following detailed description describes an exemplary embodiment in connection with a track type tractor, it should be appreciated that the description applies equally to the use of the present disclosure in other machines.

In an illustrated embodiment, the machine **100** includes a power source **102** and an operator's station or cab **104**. The machine **100** further includes an implement **108**, such as, for example, a blade or a shovel for moving earth. The cab **104** may include a user interface **110** necessary to operate the machine **100**. The user interface **110** may include, for example, one or more operator input devices **106** for propelling the machine **100** and/or controlling other machine components. The one or more operator input devices **106** may include one or more joysticks provided within the cab **104**, and adapted to receive input from an operator indicative of a desired movement of the implement **108**.

For simplification purposes, only one operator input device **106** embodied as a joystick will be discussed and shown in the figures. The user interface **110** may also include a display for conveying information to the operator and may include a keyboard, touch screen, or any suitable mechanism for receiving input from the operator to control and/or operate the machine **100**, the implement **108**, and/or the other machine components.

The implement **108** may be adapted to engage, penetrate, or cut the surface of a worksite **112** and may be further adapted to move the earth to accomplish a predetermined task. The worksite **112** may include, for example, a mine site, a landfill, a quarry, a construction site, or any other type of worksite. Moving the earth may be associated with altering the geography at the worksite **112** and may include, for example, a grading operation, a scraping operation, a leveling operation, a material removal operation, or any other type of geography altering operation at the worksite **112**.

In the illustrated embodiment, the implement **108** includes a cutting edge **114** that extends between a first end **116** and a second end **118**. The first end **116**, of the cutting edge **114** of the implement **108**, may represent a right tip or right edge of the implement **108** and the second end **118**, of the cutting edge **114** of the implement **108**, may represent a left tip or left edge of the implement **108**. In an embodiment, the implement

108 may be moveable by one or more hydraulic mechanisms operatively connected to the operator input device **106** provided in the cab **104**.

The hydraulic mechanisms may include one or more hydraulic lift actuators **120** and one or more hydraulic tilt actuators **122**, for moving the implement **108** to various positions, such as, for example, lifting the implement **108** up or lowering the implement **108** down, and tilting the implement **108** left or right. In the illustrated embodiment, the machine **100** includes one hydraulic lift actuator **120** and one hydraulic tilt actuator **122** on each side of the implement **108**. The illustrated embodiment shows two hydraulic lift actuators **120**, but only one of the two hydraulic tilt actuators **122** is shown (only one side shown). Moreover, the hydraulic mechanism may also include one or more hydraulic push cylinders (not shown) for pitching the implement **108** in forward or backward direction.

The power source **102** may be an engine that provides power to a ground engaging mechanism **124** adapted to support, steer, and propel the machine **100**. The power source **102** may embody an engine such as, for example, a diesel engine, a gasoline engine, a gaseous fuel-powered engine, or any other type of combustion engine known in the art. It is contemplated that the power source **102** may alternatively embody a non-combustion source of power (not shown) such as, for example, a fuel cell, a power storage device, or another suitable source of power. The power source **102** may produce a mechanical or electrical power output that may be converted to hydraulic power for providing power to the ground engaging mechanism **124**, the implement **108**, and to other machine components.

The machine **100** may further include a control system **126** operatively connected to the operator input device **106** and to the hydraulic actuators **120**, **122** for controlling movement of the implement **108**. As illustrated in FIG. 2, the control system **126** includes a load sensor **128**, a speed sensor **130**, and an implement position sensor **132**. In an embodiment, the load sensor **128** may include one or more torque sensors or pressure transducers or temperature sensors or the like, associated with the power source **102** of the machine **100** and configured to generate a load signal indicative of a loading condition of the implement **108**. Alternatively, the load sensor **128** may include strain gauges or pressure transducers coupled to the implement **108** and/or the hydraulic actuators **120**, **122** to measure and quantify an amount of dirt/material carried by the implement **108**. In some alternative embodiments, the load sensor **128** may include a system which estimates the loading condition of the implement **108** as functions of other measured parameters. Load sensors **128** are known by ordinary persons skilled in the art. The speed sensor **130** may be associated with the ground engaging mechanism **124**, and configured to generate a speed signal indicative of a machine speed. In an alternative embodiment, the speed sensor **130** may be a system associated with a GPS system. Further, the implement position sensor **132** may be associated with the implement **108** and/or the hydraulic actuators **120**, **122** and configured to generate an implement position signal indicative of a position of the implement **108**.

The control system **126** further includes a grade control system **134**, and a controller **136**. The controller **136** is adapted to receive inputs from the operator input device **106** and/or the grade control system **134** to control the movement of the implement **108** based on the loading condition of the implement **108**, the machine speed, and the position of the implement **108** individually or collectively in pre-determined combinations. The grade control system **134** and the controller **136** may include one or more control modules (e.g. ECMS,

ECUs, etc.). The one or more control modules may include processing units, memory, sensor interfaces, and/or control signal interfaces (for receiving and transmitting signals). The processing units may represent one or more logic and/or processing components used by the control system **126** to perform certain communications, control, and/or diagnostic functions. For example, the processing units may be adapted to execute routing information among devices within and/or external to the control system **126**.

According to an aspect of the present disclosure, the controller **136** may direct the implement **108** to move to a desired implement position in response to a desired position signal received from the grade control system **134**. The desired position signal is indicative of an automatically determined position of the implement **108** by the grade control system **134**. The desired position signal indicative of the automatically determined position of the implement **108** may include a desired elevational signal, such as, for example, the height it is desired to have the blade **108** above the worksite **112**. The desired position signal may or may not include a desired tilt angle of the blade. In an embodiment of the present disclosure, the controller **136** may process the desired position signal, the speed signal, the implement position signal, and the load signal to output a machine control command to actuate the implement **108**. As will be apparent to a person skilled in the art, the machine control command may command an electrical current of a determined magnitude, to actuate hydraulic valves **140**, and **142** associated with the hydraulic actuators **120** and **122**, respectively.

Moreover, the automatically determined desired position of the implement **108** may be based on an input received from a site design **138**. The site design **138** may include data related to a construction surface of the worksite **112** based on an engineering design. The construction surface provided in the site design **138** may represent a ground profile indicative of an irregular three-dimension (3D) surface or a flat plane. As illustrated in FIG. 2, the construction surface is a design plane **144** that represents a desired cutting plane or a final grade for the worksite **112**. The grade control system **134** may be adapted to determine a relative desired location or position of the implement **108** with respect to the design plane **144**. Moreover, the grade control system **134** may be adapted to determine a relative location or position of the machine **100** within the worksite **112**. The relative location or position of the machine **100** and/or the implement **108** may be determined using one or more position sensors, GPS receivers, and/or laser systems, which are well-known in the art. In the illustrated embodiment, the grade control system **134** receives the input from the site design **138** indicative of the design plane **144** for the worksite **112** and the relative position of the implement **108** with respect to the design plane **144** and outputs the desired position signal as a function of these inputs.

According to an embodiment of the present disclosure, the controller **136** may include a modulation map **146**, and a closed loop implement position control **148**. The controller **136** is configured to process signals, received from the load sensor **128**, and the speed sensor **130**. The modulation map **146** may include a number of data tables **150** to store and dynamically update load factors and speed parameters associated with the machine **100**, based on the signals received from the load sensor **128** and the speed sensor **130**, respectively. In an embodiment, the load factors may represent normalized or pre-assigned values corresponding to the loading condition of the implement **108** during the operation, such as, a low load, a moderate load, and a high load. Further, the speed parameters may represent normalized or pre-assigned

values based on at least one of the machine speed, track pitch, and engine rpm. In another embodiment of the present disclosure, the modulation map **146** may include, but not limited to, a set of modulation functions based on known mathematical equations to dynamically update the data tables **150** with the load factors and the speed parameters.

Further, the closed loop implement position control **148** may be configured to calculate and minimize an error value, which is indicative of a difference between the position of the implement **108** determined by the implement position sensor **132** and the automatically determined desired position of the implement **108** by the grade control system **134**. The closed loop implement position control **148** may include an adder **152** adapted to combine or process the desired position signal, and the implement position signal to output an implement position error signal. The implement position error signal is indicative of the error value based on the implement position signal and the desired position signal. It will be apparent to a person having ordinary skill in the art that, the adder **152** may act as an electronic signal multiplier or an electronic mixer that combines two or more electrical or electronic signals to output a composite signal. The adder **152** may include transistors and/or diodes arranged in a circuit to achieve the purpose.

According to an embodiment of the present disclosure, the closed loop implement position control **148** may include a proportional-integral-derivative controller (PID controller) using a PID controller algorithm well known in the art. The closed loop implement position control **148** may include a proportional control **154**, an integral control **156**, and a derivative control **158**. It may be apparent to a person having ordinary skill in the art that, the PID controller algorithm may include a proportional gain factor (P), an integral gain factor (I), and a derivative gain factor (D) associated with the proportional control **154**, the integral control **156**, and the derivative control **158** respectively. The PID controller may scale the error value as a function of the machine speed and/or the loading condition of the implement. In an embodiment illustrated, the proportional gain factor (P), the integral gain factor (I), and the derivative gain factor (D) may include a dynamic proportional gain (G_P), a dynamic integral gain (G_I), and a dynamic derivative gain (G_D) which may be determined as a function of the load signal and the speed signal.

Further, PID controller algorithm may include calculating and generating the machine control command as a function of a pre-determined combination of the proportional gain factor (P), the integral gain factor (I), the derivative gain factor (D), and the implement position error signal. The machine control command may attempt to minimize the error value, the difference between the position of the implement **108** and the automatically determined position of the implement **108**, by controlling the current to actuate hydraulic valves **140**, and **142** associated with the hydraulic actuators **120** and **122**, respectively. The controller **136** may further include a look-up table **160** including, but not limited to, a set of modulation functions or a pre-defined look-up table for validating the machine control command and output electric signals corresponding to the current to actuate hydraulic valves **140**, and **142**.

FIG. 3 illustrates an exemplary modulation map **146**, according to an embodiment of the present disclosure. As illustrated, the modulation map **146** may include a set of two-dimensional arrays **162**, **164**, and **166** to store the dynamic proportional gain (G_P), the dynamic integral gain (G_I), and the dynamic derivative gain (G_D) corresponding to various values of the load factors and speed parameters stored in the data tables **150**. In an exemplary embodiment, the

two-dimensional array **162** may include values for the dynamic proportional gain (G_P) corresponding to a pre-determined combinations of load factors and speed parameters. Similarly, the two-dimensional arrays **164**, **166** may include values for the dynamic integral gain (G_I), and the dynamic derivative gain (G_D), respectively, corresponding to the pre-determined combinations of load factors and speed parameters.

According to another aspect of the present disclosure, the controller **136** may also direct the implement **108** to move to an operator determined position in response to an operator input signal received from the operator input device **106**. The operator determined position is indicative of a position representing an operator's desired movement of the implement **108**. The operator input signal may also include an elevational signal, such as, for example, a lower implement signal or a raise implement signal. The operator inputs signal indicative of the operators' desired movement of the implement **108** may also include a tilt signal, such as, for example, tilt left and tilt right signals. In an embodiment of the present disclosure, the controller **136** may process the operator input signal and the load factor received from the data table **150** to output the machine control command to move the implement **108**.

Further, the controller **136** is adapted receive the operator input signal generated by the operator input device **106** or the grade control signal generated by the grade control system **134**, and generate the machine control command to move the implement **108** to the operator determined position or pre-determined target position, respectively. Thus, the machine control command actuates the hydraulic actuators **140**, **142** to move the implement **108** to the corresponding target position. Moving the implement **108** may include a cut to the corresponding target position or a lift to the corresponding target position.

INDUSTRIAL APPLICABILITY

The industrial applicability of the systems and methods for controlling the implement **108** to maximize machine productivity described herein will be readily appreciated from the foregoing discussion. Although, the machine **100** is shown as a track-type tractor, the machine **100** may be any type of machine that performs at least one operation associated with for example mining, construction, and other industrial applications. Moreover, the systems and methods described herein can be adapted to a large variety of machines and tasks. For example, backhoe loaders, skid steer loaders, wheel loaders, motor graders, and many other machines can benefit from the systems and methods described.

Conventional machines may use either the operator input signal or the desired position signal from the automatic grade control system to control the movement of the implement **108**. Varying loading conditions of the implement **108** and speeds of the machine **100** may change the natural frequencies of the machine **100** and/or implement **108**. Conventional control systems associated with the implement **108** are designed with fixed proportional, integral and derivative gains and it may become unstable when the machine speed and/or the loading condition of the implement **108** are in some ranges. In such cases, the final grade or grading quality may be not close to a desired one as the implement **108** or the machine **100** may experience unanticipated resonance at a given machine speed and/or the loading condition of the implement **108**. In an aspect of the present disclosure, the control system **126** receives the inputs corresponding to the load factor/speed parameters and controls the movement of

the implement **108** to achieve the final grade as a function of varying machine speed and/or the loading conditions of the implement **108**.

In accordance with the various embodiments, the control system **126** is adapted to process the desired position signal generated by the grade control system **134** or the operator input devices **106**, the load signal, and the speed signal to generate the machine control command to move the implement **108**. FIG. **4** illustrates a process flow diagram for an exemplary method **400** to control a movement of the implement **108**, according to an aspect of the present disclosure. The method **400** may be implemented by the controller **136**.

At step **402** of the method **400**, the controller **136** is adapted to determine the desired implement position. The desired implement position may be determined either by the operator input device **106** or by the automatic grade control system **134**. In one embodiment, depicted by step **404**, where the desired implement position is determined by the operator input device **106**, for example when an operator may move a joystick to indicate a position he/she desired the implement **108** to move to. In another embodiment, depicted by step **406**, where the desired implement position is determined by the automatic grade control system **134**, the grade control system **134** generates the desired implement position signal. The method **400** proceeds from step **402** to step **408**.

At step **408**, the controller **136** senses an actual position of the implement **108** as a function of the implement position signal generated by the implement position sensor **132**. In an embodiment of the present disclosure, the method **400** may also include receiving various signals/inputs corresponding to a dirt/material condition of worksite **112**.

At step **410** the controller **136** is configured to sense the machine speed as a function of a speed signal generated by the speed sensor **130**. As described above, the speed parameters corresponding to the sensed machine speed may be dynamically updated in the modulation map **146**.

At step **412**, the controller **136** senses the loading condition of the implement **108** as a function of the load signal generated by the load sensor **128**. The load factors corresponding to the sensed loading condition of the implement **108** may also be dynamically updated in the modulation map **146**.

The machine **100** and/or the implement **108** may include a natural resonance at some frequencies. These natural frequencies may change depending on the machine speed and the loading condition of the implement **108**. If a closed loop control system also operates at one of the machine **100** or implement **108** natural frequencies, the closed loop control system may become unstable. Using dynamic gains, determined as a function of machine speed and the loading condition of the implement **108**, may prevent instability.

At step **414**, the controller **136** determines the dynamic proportional gain (G_P) as a function of the machine speed and the loading condition of the implement **108**. As previously described in relation to FIG. **3**, the controller **136** may include an exemplary modulation map **146**. The modulation map **146** may include the set of two-dimensional arrays **162** storing the dynamic proportional gain (G_P) corresponding to various values of the machine speed and the loading condition of the implement **108**. In one embodiment, the controller **136** may determine the dynamic proportional gain (G_P) through looking up the dynamic proportional gain (G_P) in the modulation map **146**. The method **400** proceeds to step **416**.

At step **416**, the controller **136** determines the dynamic integral gain (G_I) as a function of the machine speed and the loading condition of the implement **108**. The modulation map **146** may include the set of two-dimensional arrays **164**, storing the dynamic integral gain (G_I) corresponding to various

values of machine speed and the loading condition of the implement **108**. In one embodiment, the controller **136** may determine the dynamic integral gain (G_I) through looking up the dynamic integral gain (G_I) in the modulation map **146**. The method **400** proceeds to step **418**.

At step **418**, the controller **136** determines the dynamic derivative gain (G_D) as a function of the machine speed and the loading condition of the implement **108**. The modulation map **146** may include the set of two-dimensional arrays **166** storing the dynamic derivative gain (G_D) corresponding to various values of machine speed and the loading condition of the implement **108**. In one embodiment, the controller **136** may determine the dynamic derivative gain (G_D) through looking up the dynamic derivative gain (G_D) in the modulation map **146**. The method **400** proceeds to step **420**.

At step **420**, the controller **136** may generate the machine command signal to move the implement **108** to the desired position as a function of the desired position, the actual position, the dynamic proportional gain (G_P), the dynamic integral gain (G_I), and the dynamic derivative gain (G_D).

Aspects of this disclosure may also be applied to other machines. Although the embodiments of this disclosure as described herein may be incorporated without departing from the scope of the following claims, it will be apparent to those skilled in the art that various modifications and variations can be made. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosure. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

We claim:

1. A control system for controlling movement of an implement associated with a machine, the control system comprising:

a load sensor configured to generate a load signal indicative of a loading condition of the implement;

a grade control system configured to generate a desired implement position signal indicative of a desired implement position;

an implement position sensor configured to generate an implement position signal indicative of a position of the implement; and

a controller configured to generate a machine control command to move the implement as a function of the load signal, the desired implement position signal, and the implement position signal, wherein the controller includes a closed loop implement position control, and wherein the closed loop implement position control includes a proportional control including a dynamic proportional gain, the dynamic proportional gain determined as a function of a pre-determined load parameter.

2. The control system of claim **1** further including, a speed sensor configured to generate a speed signal indicative of a machine speed; and

wherein the machine control command is determined as a function of the speed signal.

3. The control system of claim **1**, wherein the grade control system is further configured to:

receive an input related to a design plane from a site design; determine a relative position of the implement with respect to the design plane; and

output the desired implement position signal as a function of the design plane and the relative position of the implement with respect to the design plane.

4. The control system of claim **1**, wherein the dynamic proportional gain is determined as a function of a speed signal indicative of a machine speed.

9

5. A control system for controlling movement of an implement associated with a machine, the control system comprising:

a load sensor configured to generate a load signal indicative of a loading condition of the implement;

a grade control system configured to generate a desired implement position signal indicative of a desired implement position;

an implement position sensor configured to generate an implement position signal indicative of a position of the implement; and

a controller configured to generate a machine control command to move the implement as a function of the load signal, the desired implement position signal, and the implement position signal, wherein the controller includes a closed loop implement position control configured to calculate and minimize an error value, the error value indicative of the difference between the position of the implement and the desired position of the implement, and wherein the closed loop implement position control includes an integral control including a dynamic integral gain, the dynamic integral gain determined as a function of the load signal.

6. The control system of claim 5, wherein the dynamic integral gain is determined as a function of a speed signal indicative of a machine speed.

7. A control system for controlling movement of an implement associated with a machine, the control system comprising:

a load sensor configured to generate a load signal indicative of a loading condition of the implement;

a grade control system configured to generate a desired implement position signal indicative of a desired implement position;

an implement position sensor configured to generate an implement position signal indicative of a position of the implement; and

a controller configured to generate a machine control command to move the implement as a function of the load signal, the desired implement position signal, and the implement position signal, wherein the controller includes a closed loop implement position control configured to calculate and minimize an error value, the error value indicative of the difference between the position of the implement and the desired position of the implement, and wherein the closed loop implement position control includes a derivative control including a dynamic derivative gain, the dynamic derivative gain determined as a function of the load signal.

8. The control system of claim 7, wherein the dynamic derivative gain is determined as a function of a speed signal indicative of a machine speed.

9. A method for controlling movement of an implement associated with a machine, the method comprising:

sensing a loading condition of the implement;

determining a desired implement position with a grade control system;

sensing a position of the implement; and

generating a machine control command, by a controller, to move the implement as a function of the loading condition of the implement, the desired implement position, and the position of the implement, wherein the controller includes a closed loop implement position control, and wherein the closed loop implement position control includes a proportional control including a dynamic proportional gain, the dynamic proportional gain determined as a function of a pre-determined load parameter.

10. The method of claim 9, further including:

sensing a machine speed; and

10

generating the machine control command as a function of the machine speed.

11. The method of claim 9, further including:

receiving an input related to a design plane from a site design;

determining a relative position of the implement with respect to the design plane; and

determining the desired implement position as a function of the design plane and the relative position of the implement with respect to the design plane.

12. A method for controlling movement of an implement associated with a machine, the method comprising:

sensing a loading condition of the implement;

determining a desired implement position with a grade control system;

sensing a position of the implement;

generating a machine control command, by a controller, to move the implement as a function of the loading condition of the implement, the desired implement position, and the position of the implement;

calculating and minimizing an error value with a closed loop implement position control, the error value indicative of the difference between the position of the implement and the desired implement position;

determining a proportional gain factor for a proportional scaling of the error value as a function of the loading condition of the implement; and

generating the machine control command as a function of the proportional gain factor.

13. The method of claim 12, further including:

sensing a machine speed; and

determining the proportional gain factor as a function of the machine speed.

14. A method for controlling movement of an implement associated with a machine, the method comprising:

sensing a loading condition of the implement;

determining a desired implement position with a grade control system;

sensing a position of the implement;

generating a machine control command, by a controller, to move the implement as a function of the loading condition of the implement, the desired implement position, and the position of the implement;

calculating and minimizing an error value with a closed loop implement position control, the error value indicative of the difference between the position of the implement and the desired implement position;

determining an integral gain factor for an integral scaling of the error value as a function of the loading condition of the implement; and

generating the machine control command as a function of the integral gain factor.

15. The method of claim 14, further including:

sensing a machine speed; and

determining the integral gain factor as a function of the machine speed.

16. A method for controlling movement of an implement associated with a machine, the method comprising:

sensing a loading condition of the implement;

determining a desired implement position with a grade control system;

sensing a position of the implement;

generating a machine control command, by a controller, to move the implement as a function of the loading condition of the implement, the desired implement position, and the position of the implement;

calculating and minimizing an error value with a closed
loop implement position control, the error value indica-
tive of the difference between the position of the imple-
ment and the desired implement position;
determining a derivative gain factor for a derivative scaling 5
of the error value as a function of the loading condition
of the implement; and
generating the machine control command as a function of
the derivative gain factor.
17. The method of claim 16, further including: 10
sensing a machine speed; and
determining the derivative gain factor as a function of the
machine speed.

* * * * *